COOLING APPARATUS BOILING AND CONDENSING REFRIGERANT WITH LOW HEIGHT AND EASILY ASSEMBLED

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a cooling apparatus for cooling a heat-generating member such as a semiconductor device, or in particular to a cooling apparatus boiling and condensing a refrigerant for cooling a heat-generating member, such as a semiconductor device, by the boiling heat transfer through a refrigerant.

The present applicant has previously proposed, in the prior art, a cooling apparatus boiling and condensing a refrigerant (which may hereinafter be referred to simply as the cooling apparatus) designated by numeral 100 in Fig. 46. The cooling apparatus 100 has a multilayer structure of a plurality of stacked tabular members with a plurality of apertures, and comprises a refrigerant bath section 110, a heat exchange section 120 and a refrigerant diffusion section 130. A refrigerant path 101 communicates between the refrigerant bath section 110, the heat exchange section 120 and the refrigerant diffusion section 130. Also, cooling water paths 102 are formed in the heat exchange section 120. A heat-generating member 10 is mounted on the lower surface of the refrigerant bath section 110. The refrigerant in the refrigerant bath section 110 is boiled and gasified by the heat-generating member 10, and rises through the heat exchange section 120. After being diffused in the refrigerant diffusion section 130, the refrigerant flows down the heat exchange section 120. In the process, the refrigerant is condensed into liquid state by the cooling water flowing through the cooling water paths 102 and returns to the refrigerant bath section 110. In this way, the heat of the heat-generating member 10 is

transferred from the refrigerant to the cooling water thereby to cool the heat-generating member 10.

This configuration eliminates both the need of the tubes and the fins thus far used for the heat exchange section 120 and the need of assembling and inserting the tubes into the refrigerant bath section 110. As a result, the strict dimensional control of the parts is not required, and the parts production is facilitated. Also, the employment of the multilayer structure makes possible the assembly work to proceed from one direction and therefore facilitates the automation of the assembly process. Further, the elimination of the conventionally required tubes also eliminates the need of a structure for restricting the insertion length of the tubes inserted into the refrigerant bath section 110. Thus, the volume ratio which the refrigerant bath section 110 represents, of the whole cooling apparatus 100, is reduced and the heat radiation area is increased for an improved radiation performance.

With the cooling apparatus 100 shown in Fig. 46, however, in the case where a second heat-generating member is mounted on the upper surface of the refrigerant diffusion section 30 from the viewpoint of the mountability and effective space utilization of the heat-generating member 10, the refrigerant vapor in the refrigerant diffusion section 130 constitutes a thermal resistance so that the liquefied refrigerant in the refrigerant bath section 110 fails to be boiled and the heat-generating member mounted on the upper surface of the refrigerant diffusion section 130 cannot be cooled.

Also, in the cooling apparatus 100, the multilayer structure of the tabular members can easily realize a complicated internal structure having the refrigerant path 101 and the cooling water paths 102 of the heat exchange section 120. Nevertheless, the refrigerant bath section 110 or the refrigerant diffusion

section 130, through which only the refrigerant flows, leads to a high assembly cost (greater number of assembly steps). Further, the provision of a plurality of the apertures in the tabular members increases the wasteful material and poses the problem of an increased material cost.

A conventional cooling apparatus 200 of the prior art shown in Fig. 47, on the other hand, is configured of a multilayer structure including a plurality of plate members 210, 220, 230, and comprises a refrigerant bath section 201, a heat exchange section 202 and a refrigerant diffusion section 203, wherein the apertures (not shown) formed in the plate members 230 make up a hermetically enclosed space (not shown) for sealing the refrigerant therein and a cooling water path (not shown) through which the cooling water flows from an external source. A cooling water inlet 206 and a cooling water outlet 207 at the ends of the cooling water path are formed on the upper surface of the multilayer structure of the plate members. The inlet 206 is connected with an inlet pipe 260, and the outlet 207 is connected with an outlet pipe 270.

In cooling the heat-generating member 10 mounted on the lower surface of the refrigerant bath section 201, the refrigerant stored in the refrigerant bath section 201 is boiled and gasified by the heat received from the heat-generating member 10, so that the latent heat of the refrigerant vapor is discharged into the cooling water in the heat exchange section 202 introduced from the inlet pipe 260 and, through the cooling water path, flowing out from the outlet pipe 270.

The conventional cooling apparatus 200 described above poses the problem that, as the cooling water inlet 206 and the cooling water outlet 207 are formed on the upper surface of the multilayer structure, the real height of the cooling apparatus 200 along the direction of the stack of the plate members is increased

once the pipe members such as the inlet pipe 260 and the outlet pipe 270 are connected. An increased height of the cooling apparatus 200 may inconveniently make it impossible to install the apparatus in a space with a small height.

SUMMARY OF THE INVENTION

In view of the problems described above, an object of this invention is to provide a cooling apparatus boiling and condensing a refrigerant, in which a heat-generating member, if mounted on the upper surface, can be cooled.

Another object of the invention is to provide a cooling apparatus, in which the height along the stack of plate members is suppressed.

Still another object of the invention is to provide a cooling apparatus boiling and condensing a refrigerant, which can be produced with a lower assembly cost and a lower material cost.

In order to achieve the objects described above, the present invention employs the technical means described below.

According to a first aspect of the invention (Figs. 1 to 10), there is provided a cooling apparatus boiling and condensing refrigerant comprising an upper plate (110), a lower plate (120), a plurality of intermediate plates (130A to 130E) stacked between the upper plate (110) and the lower plate (120), a plurality of apertures (131 to 134) formed in the intermediate plates (130A to 130E), a first space (140) formed by the plurality of the apertures (131 to 134) for sealing a refrigerant, a second space (150) formed in proximity to the first space (140) through which an external cooling fluid flows, and a heat-generating member (10) mounted at least on the outer surface of the lower plate (120) among the lower plate (120) and the upper plate (110), wherein heat is exchanged between the refrigerant boiled by the heat of the heat-generating member (10) and the external cooling

fluid, and wherein the upper portion (150A) of the second space (150) is formed in proximity to the inner surface of the upper plate (110).

In this cooling apparatus (100), the heat of the heat-generating member (10a) mounted on the outer surface of the lower plate (120) is transferred to the refrigerant in the first space (140) and further exchanged with the external cooling fluid in the second space (150) in proximity to the outer surface of the upper plate (110) thereby to cool the heat-generating member (10a). A heat-generating member (10b), if mounted on the outer surface of the upper plate (110) to improve the mounting density and secure effective space utilization, etc. can be cooled by the external cooling fluid in the second space (150) in proximity to the outer surface of the upper plate (110).

In a first modification of the first aspect of the invention, an area where the upper portion (150A) of the second space (150) is in proximity to the inner surface of the upper plate (110) corresponds to the area of the heat-generating member (10b) which may be mounted on the upper plate (110), so that the heat-generating member (10b) mounted on the upper plate (110) can be cooled more effectively.

In a second modification of the first aspect of the invention, the lower portion (150B) of the second space (150) may be formed in proximity to the inner surface of the lower plate (120), so that the heat-generating member (10a) mounted on the lower plate (120) can be cooled also by the external cooling fluid in the second space (150) and therefore the amount of the refrigerant sealed in the first space (140) can be reduced.

In a third modification of the first aspect of the invention, the first space (140) includes a plurality of first small spaces (141) communicating with each other, the second space (150) includes a plurality of second small spaces (151) communicating with each other, and the

first small spaces (141) and the second small spaces (151) are arranged to coexist and to be mixed each other.

As a result, the area in which the refrigerant boiled and gasified in the first space (140) and the external cooling fluid in the second space (150) are in proximity to each other is increased for an improved heat exchange efficiency.

In a fourth modification of the first aspect of the invention, the heat-generating members (10) each has a plurality of heat sources (11) therein, and the heat sources (11) of the heat-generating member (10a) mounted on the lower plate (120) are preferably arranged in positions corresponding to the first small spaces (141).

As a result, the refrigerant in the first space (140) is easily boiled and gasified, and the heat exchange with the external cooling fluid in the second space (150) is promoted for an improved cooling performance.

In a fifth modification of the first aspect of the invention, the heat sources (11) of the heat-generating member (10b) mounted on the upper plate (110) are preferably arranged in a position corresponding to the second small spaces (151).

As a result, the thermal resistance between the heat sources (11) of the heat-generating member (10b) and the external cooling fluid in the second space (150) is reduced, thereby improving the cooling performance.

According to a second aspect of the invention, there is provided a cooling apparatus (Figs. 11 to 18) having a multilayer structure of a plurality of plate members (110, 120, 130), and a fluid path (105) formed in the multilayer structure having the plurality of the plate members (110, 120, 130) and communicating with an external environment through communication ports (106, 107);

wherein the heat of the heat-generating members (10) mounted on the surfaces of the cooling apparatus is

discharged into a heat receiving medium introduced in and out by way of the communication ports (106, 107) and flowing through the fluid path (105) thereby to cool the heat-generating members (10); and

wherein the communication ports (106, 107) are formed on the surface of the end portion of the plate members (110, 120, 130) along the direction of extension thereof.

Even in the case where pipe members or the like are connected to the communication ports (106, 107), the height along the direction of the stack of the plate members (110, 120, 130) is hardly increased. Thus, the height along the direction of the stack of the plate members (110, 120, 130) can be suppressed.

In a first modification of the second aspect of the invention, the communication ports (106, 107) are formed as a rectangle by notches (133C, 133D) cut to the same shape in the same positions at the end portions of the plurality of adjacent ones of the plate members (130C, 130D).

This configuration eliminates both the need of forming notches at different positions at the end portions of a plurality of the plate members and the need of forming notches of different shapes. Therefore, the communication ports (106, 107) can be easily formed.

In a second modification of the second aspect of the invention, pipe members (160, 170) through which a heat receiving medium flows are projected outward from the communication ports (106, 107).

As a result, the heat receiving medium smoothly flows through the fluid path (105).

In a third modification of the second aspect of the invention, the pipe members (160, 170) are connected to the communication ports (106, 107), respectively, through a connecting member (180).

As a result, the pipe members (160, 170) can be readily coupled to the side surface of the end portions

of the plurality of the plate members (110, 120, 130).

In a fourth modification of the second aspect of the invention, each connecting member (180) is arranged in such a manner as to cover the corresponding one of the communication ports (106, 107) and has a through hole (183) into which the corresponding one of the pipe members (160, 170) is inserted.

In this configuration, the pipe members (160, 170) can be easily, securely connected to the communication ports (106, 107), respectively, by being inserted into the corresponding through holes (183) of the connecting members (180), respectively, arranged in such a manner as to cover the communication ports (106, 107).

In a fifth modification of the second aspect of the invention, each through hole (183) is circular in shape.

With this configuration, the pipe members (160, 170), which are generally cylindrical in shape, can be easily connected by insertion.

In a sixth modification of the second aspect of the invention, each connecting member (180) is formed with a projected portion (182), and the multilayer structure having a plurality of the plate members (110, 120, 130) is formed with a fitting recess (104a) adapted to be fitted with the projected portion (182) of the connecting member (180).

With this configuration, the projected portion (182) is fitted in the recess (104a) so that the connecting member (180) can be easily set in position with respect to the multilayer structure of the plurality of the plate members (110, 120, 130).

In a seventh modification of the second aspect of the invention, the connecting member (180) is a metal plate member (180) bent in L shape and formed with the projected portion (182).

With this configuration, by bending a tabular metal member into L shape in press or the like, the projected portion (182) can be easily formed.

In an eighth modification of the second aspect of the invention, the multilayer structure of a plurality of the plate members (110, 120, 130) is formed with a recess (104) conforming to the shape of the corresponding connecting member (180), and the connecting member (180) is inserted in the recess (104).

With this configuration, the projection of the connecting member (180) from the multilayer structure of the plate members (110, 120, 130) is suppressed.

In a ninth modification of the second aspect of the invention, the multilayer structure of the plurality of the plate members (110, 120, 130) includes a refrigerant bath section (101) for storing the refrigerant therein, and a heat exchange section (102) for exchanging heat between the refrigerant and a heat receiving medium flowing through the fluid path (105), wherein the refrigerant stored in the refrigerant bath section (101) receives heat from the heat-generating member (10) and is boiled and gasified, so that the latent heat of the refrigerant vapor is discharged into the heat receiving medium flowing through the fluid path (105) in the heat exchange section (102) thereby to cool the heat-generating members (10).

A cooling apparatus having a high cooling efficiency utilizing the latent heat transfer of the refrigerant is required to comprise a refrigerant bath section (101) and the like, and therefore the height along the direction of stack of the plate members (110, 120, 130) is liable to increase. This invention, in contrast, in which the height of the plate members (110, 120, 130) along the direction of stack thereof can be effectively suppressed can provide advantageous effects.

According to a third aspect of the invention, there is provided a cooling apparatus boiling and condensing a refrigerant (hereinafter, referred to as the cooling apparatus), comprising:

a refrigerant bath section (110) for storing a

refrigerant therein and having a first heat-generating member (10) mounted on the surface thereof;

a refrigerant diffusion section (130) for diffusing the refrigerant boiled by the heat received from the first heat-generating member (10); and

a heat exchange section (120) interposed between the refrigerant bath section (110) and the refrigerant diffusion section (130) and formed with a first space (121A) which communicates with the refrigerant bath section (110) and the refrigerant diffusion section (130) and through which the refrigerant flows, and a second space (122A) through which the external cooling fluid flows;

wherein the heat exchange section (120) is formed as a multilayer structure having a plurality of tabular members (120A to 120D) having apertures (121, 122) corresponding to the first space (121A) and the second space (122A), respectively; and

wherein the refrigerant bath section (110) is formed integrally by forging or casting.

As a result, the heat exchange section (120) having a complicated internal structure of the first space (121A) and the second space (122A) can be easily formed as a multilayer structure of a plurality of the tabular members (120A to 120D). Also, with regard to the refrigerant bath section (110) in which only the refrigerant flows, the multilayer of the tabular members (120A to 120D) is eliminated thereby to reduce the assembly cost, while at the same time eliminating the wasteful material corresponding to the apertures (121, 122) for a lower material cost.

In a first modification of the third aspect of the invention, at least one screw portion (114), for mounting the first heat-generating member (10) to the refrigerant bath section (110), and a mounting portion for mounting a predetermined mating member thereto can be easily formed on the refrigerant bath section (110). Specifically, in

the case where the refrigerant bath section (110) has a multilayer structure of a plurality of tabular members, the screw portion would be required to be formed after forming the whole of the cooling apparatus (100) integrally. This requires a very difficult machining process. Also, in forming the mounting portion, another member is required to be coupled.

In a second modification of the third aspect of the invention, first ribs (115) for enlarging a heat transfer area with the refrigerant are integrally formed in the refrigerant bath section (110), thereby improving the performance inexpensively (promoting the boiling of the refrigerant).

In a third modification of the third aspect of the invention, a plurality of first depressions (116) are formed in the internal bottom surface of the refrigerant bath section (110).

As a result, even in the case where the cooling apparatus (100) is mounted on a vehicle, for example, and is tilted by the position of the vehicle while running, all the refrigerant is not concentrated at a lower place but can be held in the first depressions (116), thereby preventing the deterioration of the boiling action of the refrigerant. The first depressions (116), unlike the multilayer structure, can be easily formed at the same time as the refrigerant bath section (110).

In a fourth modification of the third aspect of the invention, the first ribs (115) are arranged in a plurality of the first depressions (116), respectively.

As a result, in the case where the cooling apparatus (100) is tilted, the area of heat transfer from the first heat-generating member (10) through the first ribs (115) to the refrigerant held in the first depressions (116) is increased thereby to promote the boiling of the refrigerant.

In a fifth modification of the third aspect of the invention, the first ribs (115) are formed as concavities

open to the outer periphery from the center of the refrigerant bath section (110).

As in the third modification of the invention described above, even in the case where the cooling apparatus (100), mounted on, for example, a vehicle, is tilted as the vehicle changes in position while running, all the refrigerant is not concentrated at a lower place, but can be held in the concave portions of the first ribs (115), thereby preventing the boiling action of the refrigerant from being reduced. Incidentally, coupled with the fourth modification of the third aspect of the invention described above, the first depressions (116) and the concave portions of the first ribs (115) combine to hold a large amount of the refrigerant, thereby further improving the effect of preventing the reduction in the boiling action of the refrigerant.

In a sixth modification of the third aspect of the invention, the refrigerant diffusion section (130) is formed integrally by forging or casting, and therefore, as in the third aspect of the invention, can be formed at low cost.

In a seventh modification of the third aspect of the invention, as in the first modification of the third aspect of the invention described above, the refrigerant diffusion section (130) is formed easily with at least one screw portion (137) for mounting the second heat-generating member (10a) to the refrigerant diffusion section (130) and a mounting portion (139) for mounting a predetermined mating member thereto.

In an eighth modification of the third aspect of the invention, the refrigerant diffusion section (130) has therein second ribs (138) extending toward the second space (122A) from the second heat-generating member (10a) into contact with the heat exchange section (120).

As a result, the heat of the second heat-generating member (10a) can be efficiently transferred to the external cooling fluid in the second space (122A) through

the second ribs (138) and, therefore, the cooling performance is improved in the case where the second heat-generating member (10a) is mounted on the refrigerant diffusion section (130) side.

In a ninth modification of the third aspect of the invention, the second ribs (138) are formed as concave portions open to the outer periphery from the center of the refrigerant diffusion section (130).

In a tenth modification of the third aspect of the invention, a plurality of second depressions (128) are formed on the surface of the heat exchange section (130) in contact with the second ribs (138), which in turn are arranged in the plurality of the second depressions (128).

As a result, in the case where the cooling apparatus (100) is tilted, the heat of the second heat-generating member (10a) can be transferred to the refrigerant held in the second depressions (128) (the refrigerant can be boiled), thereby making it possible to cool the second heat-generating member (10a) efficiently. Incidentally, coupled with the ninth modification of the third aspect, a larger amount of refrigerant can be held by the second depressions (128) and the concave portions of the second ribs (138) combined. Thus, the effect of preventing the reduction in the boiling action of the refrigerant can be improved.

In an 11th modification of the third aspect of the invention, a third space (133A) through which the external cooling fluid flows from the second space (122A) is formed in at least one of the refrigerant bath section (110) and the refrigerant diffusion section (130), and a sacrificial member (170) against the external cooling fluid is arranged on the internal surface of the refrigerant bath section (110) or the refrigerant diffusion section (130), in which the third space (133A) is formed.

As a result, in the case where the external cooling

fluid is caused to flow in the refrigerant bath section (110) or the refrigerant diffusion section (130), the entire surface covered by the sacrificial member (170) can be corroded first. Therefore, the thickness of the refrigerant container is not required to be increased unnecessarily taking the local corrosion by the external cooling fluid into consideration, thereby making it possible to improve the corrosion resistance of the refrigerant bath section (110) or the refrigerant diffusion section (130) against the external cooling fluid.

In a 12th modification of the third aspect of the invention, the sacrificial member (170) arranged on the internal surface of the refrigerant bath section (110), apart from the refrigerant diffusion section (130), has a porous structure.

As a result, the boiling of the refrigerant is promoted by increasing the heat transfer area in the refrigerant bath section (110).

The reference numerals shown in the parentheses above indicate the correspondence with specific means included in the embodiments described later.

The present invention may be more fully understood from the description of the preferred embodiments of the invention set forth below, together with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagram schematically showing a system configuration of a cooling apparatus boiling and condensing a refrigerant according to this invention.

Fig. 2 is a front view showing the external appearance of the cooling apparatus boiling and condensing a refrigerant according to a first embodiment of the invention.

Fig. 3 is a plan view showing the external appearance of the cooling apparatus boiling and condensing a refrigerant according to the first

embodiment of the invention.

Fig. 4 is a sectional view taken in line A-A in Fig. 3.

Fig. 5A is a plan view showing an upper plate.

Fig. 5B is a plan view showing an intermediate plate.

Fig. 5C is a plan view showing an intermediate plate.

Fig. 6A is a plan view showing an intermediate plate.

Fig. 6B is a plan view showing an intermediate plate.

Fig. 6C is a plan view showing an intermediate plate.

Fig. 7 is a plan view showing a lower plate.

Fig. 8 is a sectional view showing the cooling apparatus according to a second embodiment of the invention.

Fig. 9 is a sectional view showing the cooling apparatus according to a third embodiment of the invention.

Fig. 10 is a sectional view showing the cooling apparatus according to another embodiment of the invention.

Fig. 11 is a general elevational view showing a cooling apparatus according to a fourth embodiment of the invention.

Fig. 12 is an enlarged view of the portion A in Fig. 11.

Fig. 13A is a plan view showing an upper plate.

Fig. 13B is a plan view showing an intermediate plate.

Fig. 13C is a plan view showing an intermediate plate.

Fig. 14A is a plan view showing an intermediate plate.

Fig. 14B is a plan view showing an intermediate

plate.

Fig. 14C is a plan view showing an intermediate plate.

Fig. 15A is a plan view showing an intermediate plate.

Fig. 15B is a plan view showing a lower plate.

Fig. 16 is a diagram for explaining the assembled state of the essential parts of a cooling apparatus according to the fourth embodiment of the invention.

Fig. 17 is an enlarged view of the essential parts of a cooling apparatus according to a fifth embodiment of the invention.

Fig. 18 is a diagram for explaining the assembled state of the essential parts of a cooling apparatus according to a sixth embodiment of the invention.

Fig. 19 is a front view showing the external appearance of a cooling apparatus according to a seventh embodiment of the invention.

Fig. 20 is a view taken along the direction of arrow A in Fig. 19.

Fig. 21A is a plan view showing the refrigerant bath section.

Fig. 21B is a view taken along the direction of arrow B in Fig. 21A.

Fig. 22 is a plan view showing an intermediate plate 120A.

Fig. 23A is a plan view showing an intermediate plate 120B.

Fig. 23B is a plan view showing an intermediate plate 120C.

Fig. 23C is a plan view showing an intermediate plate 120D.

Fig. 24A is a plan view showing an intermediate plate 130A.

Fig. 24B is a plan view showing an intermediate plate 130B.

Fig. 24C is a plan view showing an upper plate 130C.

Fig. 25 is a front view showing the external appearance of a cooling apparatus boiling and condensing a refrigerant according to an eighth embodiment of the invention.

Fig. 26A is a plan view showing a refrigerant diffusion section.

Fig. 26B is a view taken in the direction of arrow C in Fig. 26A.

Fig. 27A is a plan view showing an intermediate plate 120D.

Fig. 27B is a plan view showing an intermediate plate 120G.

Fig. 27C is a plan view showing an intermediate plate 120F.

Fig. 28A is a plan view showing an intermediate plate 120E.

Fig. 28B is a plan view showing an intermediate plate 120C.

Fig. 28C is a plan view showing an intermediate plate 120B.

Fig. 29A is a plan view showing an intermediate plate 120A.

Fig. 29B is a plan view showing a refrigerant bath section.

Fig. 30 is a front view showing the partial external appearance of a cooling apparatus boiling and condensing a refrigerant according to a ninth embodiment of the invention.

Fig. 31A is a plan view showing a refrigerant bath section according to a tenth embodiment of the invention.

Fig. 31B is a view taken in the direction of arrow D in Fig. 31A.

Fig. 32 is a front view showing the partial external view of a cooling apparatus boiling and condensing a refrigerant according to the tenth embodiment of the invention.

Fig. 33 is a plan view showing a refrigerant bath

section according to an 11th embodiment of the invention.

Fig. 34 is a sectional view taken in line E-E in Fig. 33.

Fig. 35 is a sectional view taken in line F-F in Fig. 33.

Fig. 36 is a plan view showing a modification of the refrigerant bath section according to the 11th embodiment of the invention.

Fig. 37 is a sectional view showing the cooling apparatus boiling and condensing a refrigerant according to a modification of the 11th embodiment of the invention.

Fig. 38 is a perspective view showing the cooling apparatus boiling and condensing a refrigerant according to a 12th embodiment of the invention.

Fig. 39 is a plan view showing a refrigerant diffusion section according to the 12th embodiment of the invention.

Fig. 40A is a sectional view showing the process of fabricating the refrigerant diffusion section in Fig. 39.

Fig. 40B is a sectional view showing the process of fabricating the refrigerant diffusion section in Fig. 39.

Fig. 40C is a sectional view showing the process of fabricating the refrigerant diffusion section in Fig. 39.

Fig. 41 is a perspective view showing a modification of a sacrificial member according to the 12th embodiment of the invention.

Fig 42 is a plan view showing a first modification of the refrigerant diffusion section according to the 12th embodiment of the invention.

Fig. 43 is a plan view showing a second modification of the refrigerant diffusion section according to the 12th embodiment of the invention.

Fig. 44 is a perspective view showing a sacrificial member arranged in the refrigerant bath section according to the 12th embodiment of the invention.

Fig. 45 is a sectional view showing a refrigerant

bath section having the sacrificial member shown in Fig. 44.

Fig. 46 is a sectional view showing a conventional cooling apparatus boiling and condensing a refrigerant.

Fig. 47 is a front view showing the external appearance of a conventional cooling apparatus boiling and condensing a refrigerant.

Fig. 48 is a partially sectional elevation showing a cooling apparatus according to a 13th embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

(First embodiment)

A cooling apparatus boiling and condensing a refrigerant (hereinafter, referred to as the cooling apparatus) according to a first embodiment of the invention is explained with reference to Figs. 1 to 7. A cooling apparatus 100 operates in such a manner that a refrigerant sealed therein is boiled and gasified by the heat of heat-generating members 10 such as a semiconductor device (IGBT), and the refrigerant thus gasified is condensed into liquid phase by an external cooling fluid supplied from an external source, while at the same time discharging the latent heat of condensation into the external cooling fluid thereby to cool the heat-generating members 10.

The whole system is shown in Fig. 1, in which a radiator 1 and the cooling apparatus 100 (an inlet pipe 160 and an outlet pipe 170) are connected by pipes 3 to each other. Also, a pump 2 driven by a motor 21 is interposed between the radiator 1 and the cooling apparatus 100, so that the cooling water of the radiator 1 circulates through the interior of the cooling apparatus 100. The cooling apparatus 100 according to this invention is of water cooled type in which the cooling water of the radiator 1 corresponds to the external cooling fluid.

Of the drawings used for the description that

follows, Fig. 2 is a front view of the cooling apparatus 100, Fig. 3 a plan view of the cooling apparatus 100, Fig. 4 a sectional view taken in line A-A in Fig. 3, and Figs. 5 to 7 plan views showing plates 110, 130A to 130E and 120.

The cooling apparatus 100, as shown in Fig. 2, comprises a multilayer structure including an upper plate 110, a lower plate 120 arranged under the upper plate 110, and a plurality of intermediate plates 130A to 130E having a plurality of apertures 131 to 134 (Figs. 5 to 7) interposed between the upper plate 110 and the lower plate 120, an inlet pipe 160, an outlet pipe 170 and a refrigerant filling pipe 180. These component members are formed of aluminum or an aluminum alloy high in heat conductivity and integrally brazed to form the cooling apparatus 100.

The upper plate 110, as shown in Fig. 5A, is a substantially square tabular member formed with an inlet pipe hole 111 at the lower right corner, an outlet pipe hole 112 at the upper left corner and a refrigerant pipe hole 113 at the lower left portion, as viewed in Fig. 5A. The holes 111, 112 and 113, as shown in Figs. 2 to 4, are connected with the inlet pipe 160, the outlet pipe 170 and the refrigerant filling pipe 180, respectively.

The intermediate plates 130A, 130B and 130C, as shown in Figs. 5B, 5C and 6A, respectively, are each a tabular member having the same contour as the upper plate 110 and have a plurality of refrigerant apertures 131. The refrigerant apertures 131 are each an elliptic hole vertically long in the drawings. A plurality of the refrigerant apertures 131 are arranged in both vertically and horizontally, and when the intermediate plates 130A, 130B and 130C are stacked, adapted to be superposed one on another (the apertures 131 communicate with each other).

The intermediate plates 130A, 130B are formed with a plurality of cooling water apertures 132 in addition to

the refrigerant apertures 131. The cooling water apertures 132 include a plurality of comb-shaped inlet-side apertures 132a and a plurality of comb-shaped outlet-side apertures 132b extending horizontally, and a plurality of elliptic intermediate apertures 132c extending in vertical direction in the drawings. The intermediate apertures 132c are arranged in columns between the columns of the refrigerant apertures 131 in the drawing. The portions of the inlet-side apertures 132a and the outlet-side apertures 132b corresponding to the teeth of the comb correspond to the positions of the intermediate apertures 132c. The cooling water apertures 132 (132a, 132b, 132c) of the intermediate plates 130A, 130B are staggered from each other so that all the cooling water apertures 132 (132a, 132b, 132c) communicate with each other when the intermediate plates 130A, 130B are stacked alternately with each other.

The intermediate plates 130D, 130E, as shown in Figs. 6B and 6C, are rectangular tabular members having a contour corresponding to an area of such a size as to cover the refrigerant apertures 131 of the intermediate plates 130A to 130C. The intermediate plates 130D and 130E have a plurality of vertically long refrigerant apertures 133 and a plurality of horizontally long refrigerant apertures 134 as shown in the drawings, respectively. The refrigerant apertures 133 are formed in positions corresponding to the horizontal positions of the columns of the refrigerant apertures 131.

The holes 111, 112, 113 and the apertures 131 to 134 of the plates 110, 130A to 130E are formed by cutting, pressing or etching.

The lower plate 120, as shown in Fig. 7, is a rectangular tabular member having the same contour as the intermediate plates 130D, 130E.

As shown in Fig. 4, the intermediate plates 130A to 130E are stacked between the upper plate 110 and the lower plate 120. Specifically, a plurality of the

intermediate plates 130A and 130B are stacked alternately with each other under the upper plate 110, and the intermediate plate 130C is laid under the multilayer structure of the intermediate plates 130A and 130B. Further, the intermediate plates 130D and 130E are stacked under the intermediate plate 130C. According to this embodiment, two intermediate plates 130D, 130E, one of each, are used. Nevertheless, a set of three or more plates 130D, 130E may be used to form a multilayer structure.

Between the intermediate plates 130A to 130C, the refrigerant apertures 131 communicate in the direction of stacking thereby to form a plurality of refrigerant paths 141 as a plurality of first small spaces. Between the intermediate plates 130D and 130E, on the other hand, the refrigerant apertures 133, 134 communicate with each other at points where they cross each other to thereby form a refrigerant bath section 101. The refrigerant flow paths 141 and the refrigerant bath section 101 further communicate with each other thereby to form a refrigerant space 140 as a first space.

A predetermined amount of refrigerant is injected by way of the refrigerant filling pipe 180 communicating with the refrigerant space 140, and the refrigerant is mainly stored to fill up the refrigerant bath section 101. Flon (HFC 134a) is used as the refrigerant in this embodiment. Other refrigerants such as water, alcohol, fluorocarbon, etc. may be used as an alternative refrigerant. Incidentally, the open side of the refrigerant filling pipe 180 is sealed by welding or the like means after injecting the refrigerant.

Further, between the plurality of the intermediate plates 130A and 130B alternately stacked, the cooling water apertures 132, i.e. the inlet-side apertures 132a, the outlet-side apertures 132b and the intermediate apertures 132c communicate along both the direction of stacking and the direction of the plate surface thereby

to form a cooling water space 150 as a second space. The portion of the cooling water space 150 which is formed by the intermediate apertures 132c, for example, makes up the cooling water paths 151 as second small spaces. Incidentally, the cooling water space 150 communicates with the inlet pipe 160 and the outlet pipe 170.

As described above, the feature of this invention is the cooling water apertures 132 formed in the intermediate plates 130A, 130B immediately below the upper plate 110. Thus, the upper portions 150A of the cooling water space 150 (cooling water paths 151) are formed in proximity to the inner surface of the upper plate 110. Also, the cooling water paths 151 alternately coexist with the refrigerant paths 141 due to the arrangement of the intermediate apertures 132c and the refrigerant apertures 131.

The heat-generating member 10 is arranged on the outer surface of the upper plate 110 as well as on the outer surface of the lower plate 120, and is fastened fixedly with a bolt or the like not shown. In the description that follows, the lower heat-generating member and the upper heat-generating member are discriminated from each other by being designated by reference numerals 10a and 10b, respectively. In order to reduce the contact thermal resistance between the heat-generating members 10a, 10b and the plates 110, 120, a heat conductive grease may be applied between them.

Next, the operation and the effects of this embodiment are explained. The refrigerant in the refrigerant bath section 101 is boiled and gasified by the heat of the heat-generating member 10a, and rises along each refrigerant path 141. The refrigerant gasified is thus cooled by the cooling water flowing in the cooling water path 151, and after being condensed into liquid state mainly on the wall surface, refluxes to the refrigerant bath section 101 by its own weight. In this way, the cooling apparatus 100 transports the heat

of the heat-generating member 10a by boiling and gasification, and discharges the latent heat of condensation at the time of condensation into a liquid state, to the cooling water, thereby to cool the heat-generating member 10a.

The heat of the heat-generating member 10b, on the other hand, is discharged into the cooling water in the cooling water path 151 in proximity through the upper plate 10 thereby to cool the heat-generating member 10b.

As described above, according to this invention, the heat-generating member 10 mounted on the outer surface of the upper plate 110 to improve the mounting density and effectively utilize the space can be cooled by the cooling water in the nearby cooling water path 151.

Also, as the refrigerant paths 141 and the cooling water paths 151 are arranged alternately to coexist, the area where the cooling water and the refrigerant boiled and gasified by the heat-generating member 10a are in proximity to each other is increased for an improved heat exchange efficiency.

(Second embodiment)

A second embodiment of the invention is shown in Fig. 8. According to the second embodiment, unlike in the first embodiment described above, the area where the upper portions 150A of the cooling water spaces 150 (cooling water paths 151) are in proximity to the inner surface of the upper plate 110 corresponds to the area of the heat-generating member 10b.

As a result, the heat-generating member 10b can be cooled effectively in accordance with the mounting position and size thereof. Also, the area where the upper portions 150A of the cooling water spaces 150 are not in proximity to the upper plate 110 is formed with the refrigerant diffusion section 103, and therefore the reflux of the refrigerant boiled and gasified by the heat-generating member 10a is promoted for an improved cooling performance of the heat-generating member 10a.

(Third embodiment)

A third embodiment of the invention is shown in Fig. 9. According to the third embodiment, as compared with the first embodiment described above, the lower portions 150B of the cooling water spaces 150 are also arranged in proximity to the inner surface of the lower plate 120. Also, a plurality of device chips 11 constituting a plurality of heat sources of the heat-generating member 10a therein are arranged in positions corresponding to the positions of the refrigerant paths 141.

As a result, the heat-generating member 10a is cooled also by the cooling water in the cooling water spaces 150 (cooling water paths 151), and therefore the amount of the refrigerant sealed in the refrigerant spaces 140 can be reduced.

Also, the refrigerant in the refrigerant spaces 140 is easily boiled and gasified, and the heat exchange is promoted with the cooling water in the cooling water spaces 150 thereby to improve the cooling performance.

In the above second and third embodiments, the heat-generating member 10b mounted on the upper surface of the cooling apparatus 100 may be an inverter for compressing gas such as a refrigerant and the heat-generating member 10a mounted on the lower surface of the cooling apparatus 100 may be an inverter for propulsion.

(Other embodiments)

As compared with the first embodiment, the device chips 11 in the heat-generating member 10b are preferably arranged in a position corresponding to the positions of the cooling water paths 151, respectively, as shown in Fig. 10, whereby the thermal resistance between the device chips 11 and the cooling water can be reduced for an improved cooling performance.

The cooling apparatus 100 according to this invention is equal to the conventional one disclosed in prior art even in the case where the heat-generating member 10a is arranged only on the lower plate 120

without any heat-generating member 10b on the upper plate 110.

(Fourth embodiment)

Fig. 11 is a side view showing the whole of the cooling apparatus 100 according to this embodiment, Fig. 12 an enlarged view of the portion A in Fig. 11, and Figs. 13 to 15 plan views of the plates 110, 130A to 130F and 120, respectively.

The cooling apparatus 100 according to this embodiment comprises a refrigerant bath section 101 for storing the refrigerant, a heat exchange section 102 for exchanging heat between the boiling refrigerant heated by the heat-generating member 10 in the refrigerant bath section 101 and the cooling water providing a heat receiving medium, and a refrigerant diffusion section 103 for diffusing in horizontal direction the refrigerant vapor flowing in from the refrigerant bath section 101 through the heat exchange section 102 (Fig. 12).

The cooling apparatus 100 operates in such a manner that the refrigerant sealed therein is boiled and gasified by the heat of the heat-generating member 10 such as a semiconductor device (IGBT), and when the refrigerant vapor is condensed into liquid state by the cooling water supplied from an external source, the latent heat of condensation is discharged into the cooling water thereby to cool the heat-generating member 10. The cooling apparatus 100 is what is called the water-cooled cooling apparatus of high cooling efficiency utilizing the latent heat transfer of the refrigerant.

The cooling apparatus 100 comprises, as shown in Fig. 12: a multilayer structure including an upper plate 110, a lower plate 120 arranged under the upper plate 110, and a plurality of intermediate plates 130 (intermediate plates 130A to 130F) stacked between the upper plate 110 and the lower plate 120 and having a plurality of apertures 131A to 131F, 132C, 132D (Figs. 13 to 15); an inlet pipe 160 and an outlet pipe 170

constituting pipe members; and a connecting plate 180 constituting a connecting member. These component parts are formed of aluminum or an aluminum alloy high in heat conductivity, and are integrally brazed to form the cooling apparatus 100.

As shown in Fig. 13A, the upper plate 110 is a substantially rectangular tabular member and has two notches 114 on the right side thereof as shown in the drawing.

The intermediate plates 130A to 130F, as shown in Figs. 13B, 13C, 14A, 14B, 14C and 15A, respectively, have the same contour as the upper plate 110, and each have notches 134 in the same shape and at the same positions as the notches 114 of the upper plate 110.

Also, the intermediate plates 130A to 130F have a plurality of elliptic refrigerant apertures 131A to 131F. A plurality of the refrigerant apertures 131A to 131F are arranged in vertical or horizontal direction, and when the intermediate plates 130A to 130F are stacked, are superposed one on another (communicate with each other) thereby to form a single hermetically sealed space.

Also, as shown in Figs. 14A and 14B, the intermediate plates 130C, 130D are formed with cooling water apertures 132C, 132D in addition to the refrigerant apertures 131C, 131D described above. The cooling water apertures 132C, 132D, except for some of them, are comb-shaped and have a portion corresponding to the comb teeth extending between the refrigerant apertures 131C, 131D.

In the cooling water apertures 132C, 132D, the end portions corresponding to the forward ends of the comb teeth are arranged in staggered positions. In the case where the intermediate plates 130C, 130D are stacked on one another, the whole of the cooling water apertures 132C, 132D communicate with each other thereby to form the cooling water paths 105 providing fluid paths for a heat receiving medium.

Between the notches 134 and the cooling water

apertures 132C, 132D to the extreme right side at the upper and lower parts, in the drawing, of the intermediate plates 130C, 130D, two notches 133C, 133D are formed, respectively, to establish communication. The notches 133C, 133D are formed in the same shape and at the same position of the intermediate plates 130C, 130D. When the intermediate plates 130A to 130F are stacked, therefore, the rectangular inlet 106 and the rectangular outlet 107 described later are formed.

The lower plate 120, as shown in Fig. 15B, is a tabular member having the same contour as the upper plate 110. The lower plate 120 is formed with notches 124 at the same positions as and deeper (horizontally longer in the drawing) than the notches 114 of the upper plate 110.

As shown in Fig. 12, the intermediate plates 130A to 130F are stacked between the upper plate 110 and the lower plate 120. Specifically, between the upper plate 110 and the lower plate 120, there are stacked, from the upper plate 120 side down, two intermediate plates 130A, one intermediate plate 130B, six intermediate plates including three intermediate plates 130C and three intermediate plates 130D alternating with each other, one intermediate plate 130B, one intermediate plate 130E and two intermediate plates 130F.

With this multilayer configuration, a space for storing the refrigerant is formed by the refrigerant apertures 131E, 131F in the refrigerant bath section 101 including the four lowest plate members.

In the heat exchange section 102 formed of eight plate members thereabove, refrigerant paths communicating with the refrigerant storage space of the refrigerant bath section 101 are formed of the refrigerant apertures 131B, 131C, 131D. At the same time, the cooling water paths 105 (Fig. 14, not shown in Fig. 12) having the inlet 106 and the outlet 107 providing communication ports with the exterior, at the both ends of the cooling water paths are formed by the cooling water apertures

132C, 132D.

Further, refrigerant paths communicating with the refrigerant paths of the heat exchange section 102 for diffusing the refrigerant vapor in horizontal direction are formed by the refrigerant apertures 131A in the refrigerant diffusion section 103 formed of the three uppermost plate members.

Once the plates 110, 130, 120 are stacked, as described above, and, as shown in Fig. 16, a recess 104 corresponding to the shape of the connecting plate 180 described later is formed by the notches 114, 134, 124 at the end surface of the multilayer structure of the plates 110, 130, 120.

The connecting plate 180 is a metal plate member formed by bending a flat plate member into an L shape in a press or the like, and includes a flat surface portion 181 and a projected portion 182 projected in the direction perpendicular to the flat surface portion 181. As shown in Fig. 16, the flat surface portion 181 of the connecting plate 180 is formed with a circular through hole 183 into which the pipe members including the inlet pipe 160 and the outlet pipe 170 (the outlet pipe 170 is not shown in Fig. 16) are to be inserted.

The connecting plate 180 is arranged in the recess 104 at the end surface of the multilayer structure of the plates 110, 130, 120. Then, the flat surface portion 181 covers the inlet 106 or the outlet 107 (the outlet 107 is not shown in Fig. 16) in the recess 104 while, at the same time, the whole area of the through hole 183 is laid inside of the outer periphery of the inlet 106 or the outlet 107, as the case may be. In Fig. 16, the internal configuration of the inlet 106 is not shown.

Incidentally, the notches 124 of the lower plate 120 are deeper than the notches 114, 134 of the other plates 110, 130 and are formed in the lowest layer of the recess 104, thereby forming a fitting recess 104 for fitting the projected portion 182 of the connecting plate 180.

The inlet pipe 160 and the outlet pipe 170 have the same shape and make up substantially cylindrical piping members of an aluminum alloy material for connecting to the external pipe.

The upper plate 110 and the lower plate 120 are formed of an aluminum material for its heat conduction characteristics, while the intermediate plates 130 are formed of a clad material with a brazing material layer formed on the surface of a base metal of an aluminum alloy material. A brazing material is cladded also on the inner surface of the connecting plate 180 made of an aluminum alloy material.

In forming the cooling apparatus 100, as shown in Fig. 16, the upper plate 110, the intermediate plates 130 (130A to 130F) and the outer plate 120 are stacked and the connecting plate 180 is inserted in the recess 104 of the multilayer structure. Then, the end portions of the inlet pipe 160 and the outlet pipe 170 (not shown) are inserted in the through hole 183 of the connecting plate 180.

In the process, a brazing material 190 is supplied between the connecting plate 180 and the inlet pipe 160 and the outlet pipe 170. This assembly, once complete, is held with a jig or the like and integrally brazed by heat.

Though not shown, the cooling apparatus 100 formed this way has a filling pipe communicating with the internal refrigerant storage space. A predetermined amount of refrigerant is injected into the internal spaces through the filling pipe, and after injection, the forward end of the filling pipe is hermetically sealed off. Flon (HFC 134a) is used as the refrigerant.

With reference to the configuration described above, the operation of the cooling apparatus 100 according to this embodiment is briefly explained. The refrigerant in the refrigerant bath section 101 is boiled and gasified by the heat of the heat-generating members 10, and rises

along the refrigerant paths in the heat exchange section 102. The refrigerant is cooled by the cooling water flowing in the cooling water paths 105 and, after thus being condensed into liquid state mainly on the wall surface of the refrigerant paths, refluxes to the refrigerant bath section 101 by its own weight.

The refrigerant vapor that has failed to be condensed while rising along the refrigerant paths in the heat exchange section 102 is diffused by the refrigerant paths in the refrigerant diffusion section 103, and falls down mainly along the refrigerant paths smaller in upward pressure in the heat exchange section 105. The refrigerant then is cooled and condensed into liquid state by the cooling water flowing in the cooling water paths 105 and refluxes to the refrigerant bath section 101.

With the configuration and operation described above, the inlet 106 and the outlet 107 are formed in the surface of the end portion of the plates 110, 120, 130 along the direction of extension thereof (the direction perpendicular to the direction of stacking), and the inlet pipe 160 and the outlet pipe 170 are projected outward from the inlet 106 and the outlet 107, respectively. Therefore, the substantial height along the direction of stacking of the plate members 110, 120, 130 is not increased.

Also, in the case where an electronic part is required to be mounted on the upper surface of the cooling apparatus 100 (the surface of the upper plate 110), the inlet pipe 160 and the outlet pipe 170 do not interfere and, therefore, a sufficient mounting space can be secured.

The intermediate plates 130C, 130D making up the main parts of the heat exchange section 102 have notches 133C, 133D, respectively, of the same size and at the same positions, at the end portions thereof thereby to form the inlet 106 and the outlet 107 rectangular in

shape. As compared with the inlet 106 and the outlet 107 substantially circular in shape, therefore, the number of geometric patterns of the intermediate plates can be reduced.

In spite of the rectangular shape of the inlet 106 and the outlet 107, the employment of the connecting plate 180 covering them and having a circular through hole 183 for insertion of the inlet pipe 160 and the outlet pipe 170 cylindrical in shape can securely and readily connect the inlet pipe 160 and the outlet pipe 170 to the inlet 106 and the outlet 107, respectively.

In forming the cooling apparatus 100, the connecting plate 180 is inserted in the recess 104, and the projected portion 182 of the connecting plate 180 is fitted by being inserted in the fitting recess 104a. Before brazing, therefore, the positioning and the tacking (temporary fixing) process can be easily executed while at the same time securing a connecting area positively.

Further, after brazing, the connecting plate 180 is embedded in the multilayer structure of the plates 110, 120, 130 and, therefore, the size in the horizontal direction (the direction in which the plates extend) of the cooling apparatus 100 can be suppressed.

(Fifth embodiment)

Next, a fifth embodiment of the invention is explained with reference to Fig. 17. The fifth embodiment, as compared with the fourth embodiment, is different in the configuration of the connecting portion of the inlet pipe 160 and the outlet pipe 170. In Fig. 17, the component parts identical or similar to those of the fourth embodiment are designated by the same reference numerals, respectively, and are not described again.

As shown in Fig. 17, an L-shaped connecting plate 185 according to the fifth embodiment is projected between the upper and lower intermediate plates 130B

(heat exchange section 102) at the end surface of the multilayer structure of the plates 110, 120, 130. Unlike in the first embodiment, therefore, the plates 110, 120, 130 are not formed with the notches 114, 124, 134 except for the intermediate plate 130B arranged as the fifth layer from the bottom. The notch 134 formed in the intermediate plate 130B laid as the fifth layer from the bottom makes up a fitting recess according to this embodiment. The projected portion 187 of the connecting plate 185 is connected by being inserted and fitted in the recess 134.

With the configuration described above, as in the fourth embodiment, the substantial height along the direction of stacking of the plates 110, 120, 130 is not increased. Also, as the projected portion 187 of the connecting plate 185 fitted by being inserted in the recess 134 is held between the intermediate plates 130D and 130E on the upper and lower sides thereof, the positioning and the tacking process can be positively and easily carried out before brazing.

(Sixth embodiment)

A sixth embodiment of the invention is explained below with reference to Fig. 18. According to the sixth embodiment, unlike the fourth embodiment, no connecting plate is used at the connecting portion between the inlet pipe 160 and the outlet pipe 170. In Fig. 18, the component parts identical or similar to those of the fourth embodiment are designated by the same reference numerals, respectively, and are not described again.

Fig. 18 shows only the inlet 106 side. The inlet pipe 165 making up a pipe member projected from the inlet 106 according to the third embodiment has an end portion thereof nearer to the multilayer structure of the plates 110, 120, 130 expanded or reduced to a rectangular shape corresponding to the shape of the inlet 106.

Also, the multilayer structure of the plates 110, 120, 130 and the inlet pipe 165 are connected to each

other by a brazing material 190 supplied therebetween without using the connecting plate. In Fig. 18, the internal configuration of the inlet 106 is not shown. The outlet 107 side not shown also has the same configuration.

With this configuration, like the configuration of the fourth embodiment, the substantial height along the direction of stacking of the plate members 110, 120, 130 is not increased. Also, the number of parts is reduced due to the lack of the connecting plate.

(Other embodiments)

According to each of the embodiments described above, the number of the plate members stacked is 15 and not limited to this figure. Also, the aperture pattern of the refrigerant apertures and the cooling water apertures of the plate members is not limited to the shown ones.

According to the fourth embodiment, the connecting plate 180 is inserted in the recess 104 formed over the entire area along the direction of stacking of the multilayer structure. In the fifth embodiment, on the other hand, the connecting plate 185 is projected only from the end portion of the heat exchange section 102. Nevertheless, a recess may alternatively be formed only at the end portion of the heat exchange section 102, and the connecting plate 180 may be inserted in this recess.

With this configuration, as compared with the fourth embodiment, the positioning and tacking process can be much more easily and securely carried out before brazing.

Also, instead of flon used in each of the embodiments described above, water, alcohol or fluorocarbon, or the like, may alternatively be employed as the refrigerant.

Also, in each of the embodiments described above, the cooling apparatus 100 is of a type boiling and condensing refrigerant. As an alternative, the invention is applicable also to a cooling apparatus of such a type

that the heat of a heat-generating member is discharged directly to a heat receiving medium but not by the latent heat transfer through the refrigerant.

(Seventh embodiment)

A cooling apparatus boiling and condensing a refrigerant (hereinafter, referred to as the cooling apparatus) according to a seventh embodiment of the invention is explained with reference to Figs. 19 to 24. The cooling apparatus 100 is of water cooled type, in which the refrigerant sealed therein is boiled and gasified by the heat of heat-generating members 10 such as a semiconductor device (IGBT), and when the gasified refrigerant is condensed into liquid state by the cooling water (external cooling fluid) supplied from an external source, the latent heat of condensation is discharged into the external cooling fluid thereby to cool the heat-generating members 10.

Of the drawings referred to below, Fig. 19 is a front view of the cooling apparatus 100, Fig. 20 a plan view of the cooling apparatus 100, Fig. 21 a plan view and a front view of the refrigerant bath section 210, and Figs. 22 to 24 plan views of the plates 120A to 120D, 230A to 230C.

The cooling apparatus 100, as shown in Figs. 19 and 20, comprises, from the bottom up, the refrigerant bath section 210, a heat exchange section 120 and a refrigerant diffusion section 230 stacked in that order, an inlet pipe 140 and an outlet pipe 150 arranged on the upper surface (intermediate plate 120D) of the heat exchange section 120, and a refrigerant filling pipe 160 on the upper surface (upper plate 230C) of the refrigerant diffusion section 230. These component parts are formed of aluminum or an aluminum alloy high in heat conductivity and integrally brazed thereby to form the cooling apparatus 100.

The refrigerant bath section 210 constitutes a first feature of this invention and, unlike the heat exchange

section 120 and the refrigerant diffusion section 230 described later, is integrally formed by cold forging (or casting) as shown in Figs. 19 and 21.

Specifically, the refrigerant bath section 210 is a container-like portion so formed that a side wall 212 is arranged on the outer periphery of a rectangular bottom surface portion 211 with a space formed inside. On the left and right sides of Fig. 3, a plurality of (12 in this case) thick cylindrical potions 213 are expanded into the inner space from the side wall 212 and projected in the direction away from the bottom surface area. The thick portions 213 are formed with a plurality (12 in this case) of screw portions 214 from the lower side of the bottom surface portion 211. The cylindrical projections of the thick portions 213 are accommodated in the cooling water apertures 122 (the inlet aperture 122a and the outlet aperture 122b), described later, of the heat exchange section 120.

Further, a plurality of ribs (corresponding to the first ribs according to this invention) 215 are integrally formed and projected from the bottom surface portion 211 toward the aperture side in horizontal direction in Fig. 21. The projected end portion of each rib 214 is located at the same position as the aperture-side end portion of the side wall 212, and a gap is formed between the longitudinal end of the rib 215 and the side wall 212.

A heat-generating member (corresponding to the first heat-generating member according to the invention) 10 is arranged and fastened fixedly by bolts 11 on the lower surface of the refrigerant bath section 210. In order to reduce the contact heat resistance between the heat-generating member 10 and the refrigerant bath section 210, a heat conductive grease may be interposed between them.

The heat exchange section 120 constitutes a second feature of the invention, and as shown in Figs. 19, 22

and 23, is formed of a plurality of intermediate plates 120A to 120D in stack. Specifically, the intermediate plate 120A is arranged on the upper surface of the refrigerant bath section 210. The intermediate plates 120B and the intermediate plates 120C are arranged alternately with each other on the upper surface of the intermediate plate 120A, and the intermediate plate 120D is arranged on the multilayer structure of the intermediate plates 120B and 120C. The intermediate plate 120A is coupled in contact with the end portion far from the bottom surface portion of the ribs 215 and the side wall 212 of the refrigerant bath section 210. The end portion far from the bottom surface of the ribs 215 is coupled at a position between the refrigerant apertures 121 (described later) of the intermediate plate 120A.

The intermediate plates 230A to 230D are each a rectangular tabular member having the same contour as the refrigerant bath section 210 and have a plurality of refrigerant apertures 121. The refrigerant apertures 121 are elliptic holes extending in horizontal direction in the drawing. A plurality of the refrigerant apertures 121 are arranged both horizontally and vertically in such a manner as to be superposed one on another (communicate with each other) when the intermediate plates 230A to 230D are stacked one on another.

The intermediate plate 120A is formed with a plurality of (12 in this case) thread bypass holes 123 are formed through the cylindrical thick portions 213 of the refrigerant bath section 210.

In addition to the refrigerant apertures 121, cooling water apertures 122 are formed in the intermediate plates 230B and 230C. The cooling water apertures 122 include an inlet-side aperture 122a and an outlet-side aperture 122b extending in comb-like form vertically in the drawing and elliptic intermediate apertures 122c extending horizontally in the drawing.

The intermediate apertures 122c are interposed between the refrigerant apertures 121 vertically in the drawing. The portions of the inlet-side aperture 122a and the outlet-side aperture 122b corresponding to the comb teeth are located at positions corresponding to the intermediate apertures 122c. The end portions of the cooling water apertures 122 (122a, 122b, 122c) of the intermediate plates 230B, 230C are staggered.

Further, the intermediate plate 120D is formed with an inlet pipe hole 124 at the upper right part and an outlet pipe hole 125 at the lower left part in the drawing. The pipe holes 124 and 125 are coupled with the inlet pipe 140 and the outlet pipe 150, respectively, as shown in Figs. 19 and 20.

In the heat exchange section 120, the refrigerant apertures 121 communicate with each other along the direction of stack thereby to form a plurality of first spaces 121A. The first spaces 121A communicate with the internal spaces of the refrigerant bath section 210 and the refrigerant diffusion section 230 described later. In the plurality of the intermediate plates 120B, 120C stacked alternately with each other between the intermediate plates 120A and 120D, the cooling water apertures 122 including the inlet-side apertures 122a, the outlet-side apertures 122b and the intermediate apertures 122c communicate with each other in the directions both along the stack and along the plate surface thereby to form second spaces 122A. The second spaces 122A communicate with the inlet pipe 140 and the outlet pipe 150.

The refrigerant diffusion section 230, like the heat exchange section 120, is formed of a plurality of the plates 230A to 230C by stacking as shown in Figs. 19 and 24. Specifically, the intermediate plates 230A and the intermediate plates 230B are stacked alternately with each other, and an upper plate 230C is arranged on the multilayer structure of the intermediate plates 230A and

230B.

The intermediate plates 230A, 230B are rectangular tabular members having a contour corresponding to the area surrounding the refrigerant apertures 121 of the intermediate plates 120A to 120D of the heat exchange section 120. The intermediate plates 230A, 230B each have a plurality of refrigerant apertures 231, 232 formed as elongate horizontal or vertical holes in the drawing. The refrigerant apertures 231 are formed in positions corresponding to the vertical arrangement of refrigerant apertures 121 of the heat exchange section 120.

The upper plate 230C has the same contour as the intermediate plates 230A, 230B. A refrigerant pipe hole 233 communicating with the refrigerant apertures 231 or 232 is formed in the lower right part of the drawing. The refrigerant pipe hole 233 is connected with a refrigerant pipe 160, as shown in Figs. 19 and 20.

In the refrigerant diffusion section 230, an internal space is formed at each portion where the refrigerant apertures 231, 232 cross and communicate with each other. These internal spaces communicate with the refrigerant pipe 160.

The apertures 121, 122, 231, 232 and the holes 123 to 125, 233 of the plates 120A to 120D, 230A to 230C are formed by cutting, pressing, etching or the like.

A predetermined amount of refrigerant is injected from the refrigerant filling pipe 160. The refrigerant is passed from the refrigerant diffusion section 230 through the first space 121A of the heat exchange section 120 and stored mainly in the refrigerant bath section 210 to the full. Flon (HFC 234a) is used as the refrigerant. Any other alternative refrigerant such as water, alcohol and fluorocarbon may be used. The open side of the refrigerant filling pipe 160 is sealed by welding or the like means after injection of the refrigerant.

Next, the operation and effects of this embodiment are explained. The refrigerant in the refrigerant bath

section 210 is boiled and gasified by the heat of the heat-generating members 10, rises in the first space 121A and flows into the refrigerant diffusion section 230 where it is diffused. The diffused refrigerant flows down the first space 121A and, in the process, is cooled and condensed into liquid phase by the cooling water flowing in the second space 122A. The liquefied refrigerant refluxes into the refrigerant bath section 210 by its own weight. As described above, in the cooling apparatus 100, the heat of the heat-generating member 10 is transported by boiling and gasification, and the latent heat of condensation and liquefaction is discharged into the cooling water thereby to cool the heat-generating members 10.

According to this invention, the heat exchange section 120 having a complicated internal structure including the first space 121A and the second space 122A is easily formed by a multilayer structure of the intermediate plates 120A to 120D. The refrigerant bath section 210 where only the refrigerant flows is integrally formed by cold forging, thereby eliminating the multilayer structure of the plates (120A to 120D). Therefore, the assembly cost is reduced. Also, as the wasteful material corresponding to the refrigerant apertures 121 and the cooling water apertures 122 is eliminated, the material cost is reduced.

By forming the refrigerant bath section 210 integrally, the screw portions 214 for mounting the heat-generating members 10 are easily formed. In the prior art, in contrast, the refrigerant bath section 210 is formed of a multilayer structure of plates, in which case the screw portions 214 are required to be formed only after integrally forming the whole of the cooling apparatus 100, a machining process very difficult to carry out.

The ribs 215 are formed integrally in the internal space of the refrigerant bath section 210. Therefore,

the area of heat transfer with the refrigerant is easily increased and the boiling of the refrigerant is promoted (i.e. the heat exchange performance is improved). Further, as the end portion of the ribs 215 far from the bottom surface thereof is connected with the intermediate plate 120A of the heat exchange section 120, the pressure strength of the refrigerant bath section 210 is improved.

(Eighth embodiment)

An eighth embodiment of the invention is shown in Figs. 25 to 29. According to the eighth embodiment, as compared with the seventh embodiment described above, a heat-generating member (corresponding to the second heat-generating member of the invention) 10a is arranged also on the upper surface of the refrigerant diffusion section 230. By way of explanation, the component members of the cooling apparatus 100 are arranged top down sequentially in drawings (Figs. 26 to 29).

Like the refrigerant bath section 210, the refrigerant diffusion section 230, as shown in Figs. 25 and 26, is formed integrally by cold forging. Specifically, the refrigerant diffusion section 210 is a container-like component having an inner space defined by the side wall 235 formed on the outer periphery of the elliptic upper surface portion 234.

A plurality (a total of seven in this case, including three at the central area and four on the wall sides) of thick portions 236 are projected cylindrically from the transverse center of the upper surface 234 and the side walls 235 toward the side far from the upper surface. The thick portions 236 are formed with a plurality of (seven) screw portions 237 from the upper side of the upper surface 234. Further, a plurality of ribs (corresponding to the second ribs according to the invention) 238 are integrally formed in the inner space by being projected from the upper surface 234 toward the opening of the inner space and extend in horizontal direction in Fig. 26. Specifically, the ribs 238 extend

from the heat-generating member 10a toward the second space 122A of the heat exchange section 120, and the projected end of each of the ribs 238 is located at the same position as the end portion of the side wall 235 nearer to the opening. The projected end of each of the ribs 238 is connected at a position between the refrigerant apertures 121 of the intermediate plate 120D. Also, a gap is formed at the central portion and between the longitudinal end and the side wall 212 of each of the ribs 238 to facilitate the diffusion of the refrigerant.

Also, an inlet pipe hole 230a is formed at the upper right position, an outlet pipe hole 230b at the lower left position, and a refrigerant pipe hole 233 at the lower right position, in Fig. 26, of the refrigerant diffusion section 230. As shown in Fig 25, the pipe holes 230a, 230b, 233 are connected with the inlet pipe 140, the outlet pipe 150 and the refrigerant filling pipe 160, respectively.

The heat-generating member 10a is arranged and fixedly fastened by bolts 11 on the upper surface of the refrigerant diffusion section 230.

The intermediate plate 120D in contact with the refrigerant diffusion section 230 of the heat exchange section 120 is formed with a plurality of thread bypass holes 123 through which the thick portions 236 of the refrigerant diffusion section 230 are inserted, respectively. Unlike in the seventh embodiment, neither the inlet pipe hole 124 nor the outlet pipe hole 125 is formed. Also, intermediate plates 120G, 120F, 120E are added between the intermediate plate 120D and the the multilayer structure of the intermediate plats 120B and 120C alternating with each other. The intermediate plates 120G, 120F, as compared with the intermediate plates 120C, 120B, have added thereto thread bypass holes 123 through which the thick portions 236 are passed at the transversely central portion. The intermediate plate 120E, as compared with the intermediate plate 120C, is

formed with thick portions 126 for closing the thread bypass holes 123 communicating with the refrigerant diffusion section 230 at the transversely central portion thereof.

Further, harness holes 230c, 127, 117 for accommodating the harnesses (not shown) of the heat-generating members 10 arranged above and below the cooling apparatus 100 are formed at the lower right part, in the drawing, of the refrigerant diffusion section 230, the intermediate plates 120A to 120G and the refrigerant bath section 210.

As a result, as in the seventh embodiment, the refrigerant diffusion section 230 can be formed inexpensively. The screw portions 237 formed in the refrigerant diffusion section 230 are accommodated in the spaces formed by the thick portions 126 and the thread bypass holes 123 formed in the intermediate plates 120D, 120G, 120F, 120E, in such a manner as to prevent the leakage of the refrigerant and the cooling water.

The heat-generating member 10a mounted on the refrigerant diffusion section 230 is cooled by the cooling water of the heat exchange section 120 (second space 122A). The provision of the ribs 238 in contact with the intermediate plate 120D of the heat exchange section 120 in the internal space of the refrigerant diffusion section 230, however, transfers the heat of the heat-generating members 10 to the cooling water efficiently for an improved cooling performance.

(Ninth embodiment)

A ninth embodiment of the invention is shown in Fig. 30. According to the ninth embodiment, as compared with the eighth embodiment, the refrigerant diffusion section 230 is integrally formed with a mounting portion 139 for mounting a predetermined mating member.

The mounting portion 139 is formed as an expansion having a mounting hole 139a. The mounting portion 139 is used, for example, to fix the harnesses or the pipes of

the vehicle or to mount the cooling apparatus 100 on the vehicle body.

As described above, in the case where the refrigerant diffusion section 230 is formed as a multilayer structure of plates, another member is required to be connected to form the mounting portion 139. According to this embodiment, in contrast, the mounting portion can be integrally formed inexpensively. The mounting portion 139 may be arranged on the refrigerant bath section 210 instead of on the refrigerant diffusion section 230.

(Tenth embodiment)

A tenth embodiment of the invention is explained with reference to Figs. 31 and 32. According to the tenth embodiment, as compared with the seventh to ninth embodiments, a plurality of depressions (corresponding to the first depression of the invention) 116 are formed in the bottom surface portion 211 of the refrigerant bath section 210. The depressions 116 are each formed as a spherical dimple 116a.

As a result, even in the case where the cooling apparatus 100 mounted on a vehicle is tilted, for example, in accordance with the position of the vehicle while running, as shown in Fig. 32, all the refrigerant is not concentrated at a lower place but held by the dimples 116a. Thus, the boiling action of the refrigerant is prevented from being reduced. Unlike in the multilayer structure, the dimples 116a can be formed easily when forming the refrigerant bath section 210.

(11th embodiment)

An 11th embodiment of the invention is shown in Figs. 33 to 35. The feature of the 11th embodiment, as compared with the tenth embodiment described above, is the combination of the ribs 215 and the depressions 116.

In the refrigerant bath section 210 (the Fig. 33 shows the refrigerant bath section 210 turned by 90 degrees from the state shown in Fig. 31), a plurality of

the depressions 116 are formed elliptically, and the ribs 215 are arranged in the depressions 116, respectively.

As a result, as explained with reference to the tenth embodiment, in the case where the cooling apparatus 100 is tilted, the area of heat transfer from the heat-generating member 10 to the refrigerant held in the depressions 116 is increased by the ribs 215 and the boiling of the refrigerant is thus promoted.

The ribs 215 may be each formed as concavities, i.e. in the shape of U or crescent aperture open to the outer periphery from the center of the refrigerant bath section 210, as shown in Figs. 36 and 37. Of course, the depressions 116 are each so shaped as to be able to accommodate a concave rib 215.

As a result, in the case where the cooling apparatus 100 is tilted, the depressions 116 and the concave ribs 215 combine to hold a greater amount of refrigerant. Thus, the boiling action of the refrigerant is prevented from being reduced.

As shown in Fig. 37, the ribs 238 in the refrigerant diffusion section 230 may be formed similarly as concavities (as shown in Fig. 36) in such a manner as to open to the outer periphery from the center in the case where the refrigerant diffusion section 230 is formed integrally by forging and the heat-generating member 10a is mounted on the refrigerant diffusion section 230.

As a result, in the case where the cooling apparatus 100 is tilted, the refrigerant in the refrigerant diffusion section 230 can be held in the concave depressions of the ribs 238. Thus, the heat of the heat-generating member 10a can be transferred to the refrigerant held by the ribs 238 (the refrigerant can be boiled), thereby making it possible to cool the heat-generating member 10a efficiently.

Further, the intermediate plate 120D of the heat exchange section 120 may be formed with depressions 128 (corresponding to the second depressions according to the

invention) to increase the amount of the refrigerant held in a manner similar to the refrigerant bath section 210 when the cooling apparatus 100 is tilted.

(12th embodiment)

A 12th embodiment of the invention is explained with reference to Figs. 38 to 41. According to the 12th embodiment, as compared with the eighth embodiment, taking anticorrosiveness against the cooling water into account, the cooling water is rendered to flow also through the refrigerant diffusion section 230.

With the cooling apparatus 100 according to this embodiment, the inlet pipe 140 and the outlet pipe 150 through which the cooling water flows in and out are arranged on one side of the heat exchange section 120 so that the cooling water flows by making a U turn in the heat exchange section 120. Also, a thin plate having a sacrificial member on at least one of the surfaces thereof is arranged between the intermediate plates 120A to 120G making up the heat exchange section 120 (as proposed in prior art).

In the refrigerant diffusion section 230, on the other hand, a rectangular partitioning wall 230d is formed thereby to define a third space 233A (outside the partitioning wall 230d) through which the cooling water flows from the second space 122A of the heat exchange section 120. The second space 122A (cooling water aperture 122) of the heat exchange section 120 is formed at a position corresponding to the third space 233A, and the cooling water apertures 122 are formed also in the intermediate plate 120D. In this way, the second space 122A and the third space 233A communicate with each other. In the third space 233A, on the other hand, a partitioning wall 230e is formed to prevent the cooling water from shorting between the inlet pipe 140 side and the outlet pipe 150 side.

Also, a space through which the original refrigerant flows is formed as the refrigerant diffusion section 230

inside the partitioning wall 230d. This space corresponds to the first space 121A (refrigerant apertures 121) of the heat exchange section 120, so that communication is established between the two spaces.

A sacrificial member 270 for the cooling water is arranged on the inner surface of the refrigerant diffusion section 230. The sacrificial member 270 acts as an anode of a metal electrode against the refrigerant diffusion section 230, as well known, and is consumed (corroded as a sacrifice) by the electrochemical reaction thereby to lengthen the anticorrosive life of the mating refrigerant diffusion section 230. The sacrificial member 270 is formed of an aluminum material containing a predetermined amount of zinc to reduce the voltage potential against the aluminum material forming the refrigerant diffusion section 230.

The sacrificial member 270 is formed on the refrigerant diffusion section 230 in the manner shown in Fig. 40. Specifically, first, the sacrificial member 270 is clad in advance on one surface of the forging material 280 for the refrigerant diffusion section 230 (Fig. 40A). Next, the assembly is formed forging in such a manner that the side of the assembly cladded with the sacrificial member 270 is the inner surface of the refrigerant diffusion section 230 (Fig. 40B). Further, the end portions of the sacrificial member 270 to be connected with the heat exchange section 120 are cut off (Fig. 40C). This is to prevent the refrigerant or the cooling water from leaking with the progress of corrosion (sacrificial corrosion) of the connecting portion with the heat exchange section 120.

Incidentally, in order to eliminate the step of Fig. 40C, the sacrificial member 270 may be used in which holes 271 are punched in press beforehand at positions corresponding to the end portions of the sacrificial member 270 to be connected with the heat exchange section 120, as shown in Fig. 41.

With the cooling apparatus 100 having the refrigerant diffusion section 230 formed in this way, the heat-generating member 10a arranged on the refrigerant diffusion section 230 can be cooled by both the refrigerant (heat transfer to the refrigerant) and the cooling water flowing in the third space 233A.

Also, the provision of the sacrificial member 270 in the refrigerant diffusion section 230 through which the cooling water flows assures the prior corrosion of the sacrificial member 270 over the entire surface. As a result, the thickness of the refrigerant container is not required to be increased more than necessary by taking the local corrosion due to the cooling water into consideration and the corrosion resistance of the refrigerant diffusion section 230 against the cooling water is improved.

The third space 233A in the refrigerant diffusion section 230 can be variously arranged, as shown in Figs. 42 and 43, in accordance with the size and position of the heat-generating member 10a mounted on the refrigerant diffusion section 230. Fig. 42 shows an example in which the third space 233A is arranged on one longitudinal side of the refrigerant diffusion section 230, and Fig. 43 shows an example in which the third space 233A is formed over the entire internal part of the refrigerant diffusion section 230.

Also, as shown in Fig. 44, the third space may be formed in the refrigerant bath section 210, in which case the heat-generating member 10 mounted on the refrigerant bath section 210 can be cooled by both the refrigerant (heat transfer to the refrigerant) and the cooling water flowing in the third space in the refrigerant bath section 210.

The sacrificial member 270 is preferably arranged over the entire internal part of the refrigerant bath section 210 as a porous structure having a plurality of pores 272. In the third space in the refrigerant bath

section 210, therefore, the corrosion resistance is improved by the sacrificial member 270 while at the same time promoting the boiling of the refrigerant by increasing the internal heat transfer area of the refrigerant bath section 210 as shown in Fig. 45.

Incidentally, the porous structure of the sacrificial member 270 is not limited to the structure having the pores 272 but may be formed of fiber or meshed material.

(13th embodiment)

A 13th embodiment of the invention is shown in Fig. 48. A cooling apparatus (boiling and condensing a refrigerant) 100 according to the 13th embodiment has respective features of the first, the fourth and the seventh embodiments. The cooling apparatus 100 has a similar construction as those of the above-mentioned embodiments and, therefore, a detailed explanation of the construction thereof is not given here. In the cooling apparatus 100, a cooling water path 150 extends to an upper surface of the cooling apparatus 100, so that heat-generating members 10 are mounted on a lower surface thereof and the upper surface, respectively, and can be cooled. Also, communication ports of the cooling apparatus 100 communicating with outside piping are provided on side surfaces of a multiplayer structure. Further, a refrigerant bath section 210 of the cooling apparatus 100 is manufactured by casting.

While the invention has been described by reference to specific embodiments chosen for the purposes of illustration, it should be apparent that numerous modifications could be made thereto by those skilled in the art without departing from the basic concept and scope of the invention.